

The All Sky Automated Survey. The Catalog of Bright Variable Stars in the *I*-band, South of Declination $+28^\circ$

M. Sitek and G. Pojmański

Warsaw University Observatory, Al. Ujazdowskie 4, 00-478 Warszawa, Poland
e-mail:(msitek,gp)@astrouw.edu.pl

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ABSTRACT

This paper presents the results of our extensive search for the bright variable stars in approximately 30 000 square degrees of the south sky in the *I*-band data collected by $9^\circ \times 9^\circ$ camera of the All Sky Automated Survey between 2002 and 2009. Lists of over 27 000 variable stars brighter than 9 mag at maximum light, with amplitudes ranging from 0.02 mag to 7 mag and variability time-scales from hours to years, as well as corresponding light curves are provided. Automated classification algorithm based on stellar properties (period, Fourier coefficients, 2MASS *J*, *H*, *K*, colors, ASAS *V*-band data) was used to roughly classify objects.

Despite low spatial resolution of the ASAS data ($\approx 15''$) we cross-identified all objects with other available data sources. Coordinates of the most probable 2MASS counterparts are provided. 27 705 stars brighter than $I = 9$ mag were found to be variable, of which 7842 objects were detected to be variable for the first time. Brief statistics and discussion of the presented data is provided. All the photometric data is available over the Internet at <http://www.astrouw.edu.pl/~gp/asas/AsasBrightI.html>

Key words: *Catalogs – Stars: variables: general – Surveys*

1. Introduction

The All Sky Automated Survey (ASAS, Pojmański 1997) is an on-going observational project, triggered by ideas of Paczyński (1997), devoted to monitoring of the photometric variability of bright stars. It uses small, low cost automated instruments equipped with commercial CCD cameras and telephoto lenses. Two such systems are located in the southern and northern hemispheres.

This paper describes results of the analysis of data collected in the years 2002–2009 with one of the southern ASAS instruments (Pojmański 2001) located at the Las Campanas Observatory, Chile (operated by the Carnegie Institution for Science), equipped with the wide field camera ($9^\circ \times 9^\circ$, $2k \times 2k$ CCD, 200mm f/2 lens) and the *I*-band filter. Such configuration allows for photometry of sources brighter than limiting magnitude of $I \approx 14$ mag.

Preliminary catalogs of variable stars detected with the V-band instruments south of $\delta < +28^\circ$ were published earlier: Pojmański (2002, 2003), Pojmański and Maciejewski (2004, 2005), Pojmański, Pilecki and Szczygieł (2005).

2. Observations and Data Reduction

The All Sky Automated Survey collects data in the fully autonomous way (Pojmański 2001). Every night calibration frames (BIAS, DARK, FLAT) are taken and used to process scientific images. A comprehensive program is used to control observations, telescope movements, processing of images, photometry, astrometry, data transfer and backup. Final measurements are automatically added to the ASAS Photometric Catalog.

ASAS photometry is performed simultaneously using five apertures (2 to 6 pixels in diameter). Measurements obtained with the smallest one are best suited for faint stars ($I > 11$ mag), while the largest one should be used for brightest objects ($I < 8$ mag). Crowding and blending should be, however, taken into account.

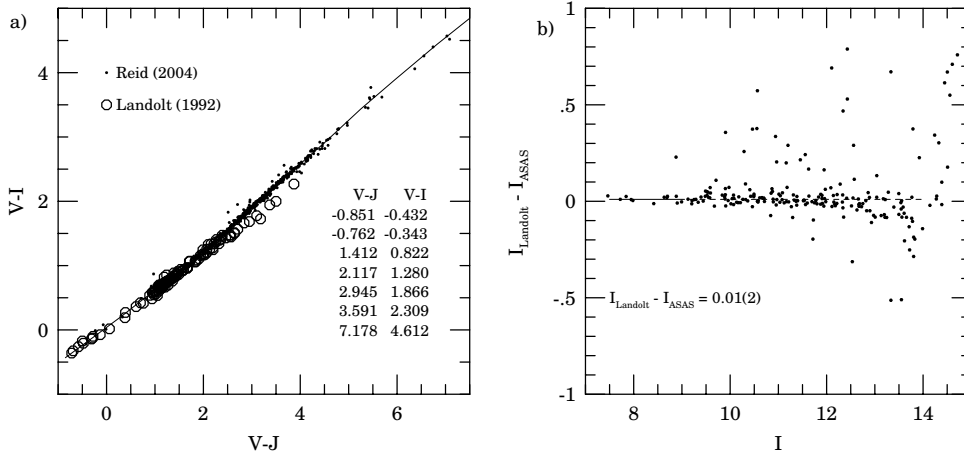


Fig. 1. *a)* $V-J$ vs. $V-I$ calibration based on compilation by Reid (see footnote). This diagram was used to convert Tycho V and 2MASS J magnitudes into I -band values, which were used to determine the zero-point of the ASAS I -band measurements. *b)* Difference between ASAS I -band magnitudes and I data for 117 standard stars of Landolt (1992).

Astrometric calibration is currently based on the ACT (Urban *et al.* 1998) catalog. Typical positional accuracy is around 0.2 pixels ($\approx 3''$).

The zero-point offset of the ASAS I -band photometry is based on the $V-J$ vs. $V-I$ relationship (Fig. 1a) for nearby stars constructed from data provided by Reid¹, based on Bessel (1990), Leggett (1992), Tycho (Perryman *et al.* 1997) and 2MASS (Skrutskie *et al.* 2006). Landolt (1992) standards which we used to check this calibration deviate somewhat (0.1–0.25 mag) from this relation for $V-I$ in

¹<http://www.stsci.edu/~inr/cmd.html>

the range 1.4–2.5. Nevertheless, since we do not include color correction in our zero-point calibration and most stars have $V - I$ values lower than 1.5 mag, we did not attempt to correct for this discrepancy. We believe that in most areas in the sky the average I -band zero-point is accurate to about 0.02 mag, as shown in Fig. 1b for Landolt standards in the equatorial area. However, due to the non-perfect flat-fielding, no color terms and blending of the stars, much larger errors can often be observed.

3. Variability Search and Classification

There are 283 000 stars brighter than $I = 9$ mag in the ASAS database. We have performed extensive search to find most of the variable objects. First, all light curves, which have more than 30 good observations, were tested for periodicity in the frequency range of 0 c/d to 25 c/d using the Analysis of Variance (AoV) test (Schwarzenberg-Czerny 1989). All stars with AoV signal larger than 10 were selected. Second, all stars showing photometric scatter larger than average were added to the list and finally, all stars brighter than 8 mag were also included. Although the period search was limited to 25 c/d only, several stars with faster variability were detected at the fraction of the true frequency (1/2 or 1/3). Light curves of all objects on the list were later displayed, both in raw form and folded with the period corresponding to the highest AoV signal. Careful inspection allowed us to reject clear artifacts, reveal blended objects, correct periods and time-scales that were initially incorrect due to aliasing.

We identified 27 705 variable stars, almost 10% of the observed population.

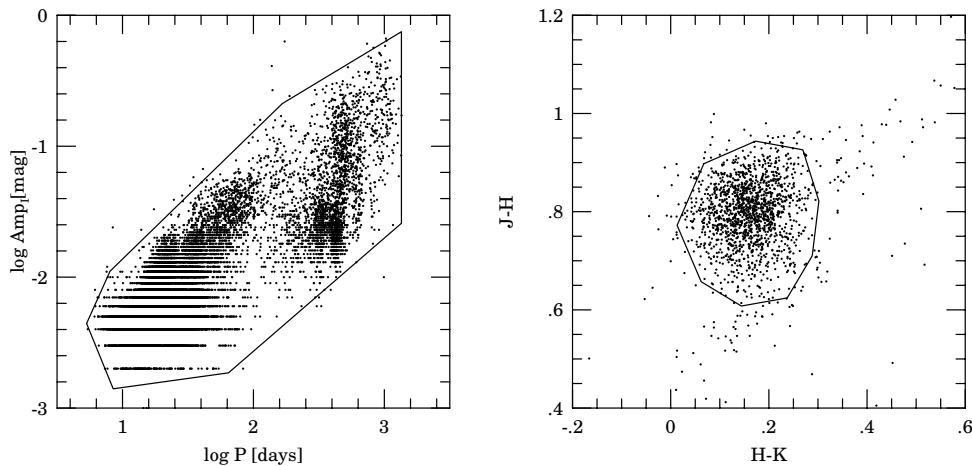


Fig. 2. Location of OGLE SMC OSARGs (Soszyński *et al.* 2004) in the $\log(P) - \log(A_I)$ (left panel) and $H-K$ vs. $J-H$ planes (right panel). Contours shown are used by our classification algorithm. We skipped points with $J - H < 0.6$ mag, which might be due to overtone Cepheids, and reddened stars.

The automated classification algorithm, described in details in Pojmański (2002, 2003, 2004), consists of a few basic steps: First, the best period is identified and Fourier coefficients of the folded light curve are calculated. Six harmonics are included. Then, J , H , K magnitudes are extracted from the 2MASS catalog. Strictly periodic variables are then classified into predefined classes (MIRA, DCEP, DSCT, RRAB, RRC, ACV, BCEP, EC, ED, ESD) using polygons defined in two-dimensional sections of multi-dimensional parameter space.

Our search revealed a large number of small amplitude variables, hence, following Wray, Eyer and Paczyński (2004) and Soszyński *et al.* (2004), we have added OSARG (OGLE Small Amplitude Red Giants) definitions to our code (Fig. 2). Separate filter detects irregular behavior, but no automated or manual algorithm is used to classify less periodic variability. Instead, all non-periodic, multi-periodic and other unusual objects are simply assigned MISC type. Additional classification is sometimes added following visual inspection of the light curve (*e.g.*, L, RCRB, RVTAU).

Since our observations were taken through the infrared I -band filter, we were able to identify a vast majority of 2MASS counterparts of our objects. For 35 objects only we did not find sources within the nominal radius of the ASAS catalog – $15''$ – mainly due to problems with correct identification of stars in the crowded fields.

Out of 27 705 variable stars detected, 19 863 were already individually investigated: 16 975 stars were detected to be variable by the ASAS V-band survey, 8483 stars are known GCVS (Kholopov 1985) objects or have individual entries in the SIMBAD database, 7842 were not earlier known to be variable.

Table 1

Number of various types of bright variable stars detected in the I -band

Type	Count	Type	Count
DCEP	230 (31)	EC	510 (83)
CW	13 (0)	ED	309 (38)
ACV	270 (100)	ESD	524 (108)
BCEP	13 (0)		
RRAB	10 (1)	M	4248 (916)
RRC	7 (0)	OSARG	7796 (2480)
DSCT	72 (7)	MISC	13703 (4078)

Number of new objects is listed in parenthesis.

In Table 1, we present the classification of variable stars into major classes. Numbers of new objects are listed in parenthesis. Figs. 3 and 4 present distribution of the major variable star classes on the sky. Differences between the populations are clearly visible.

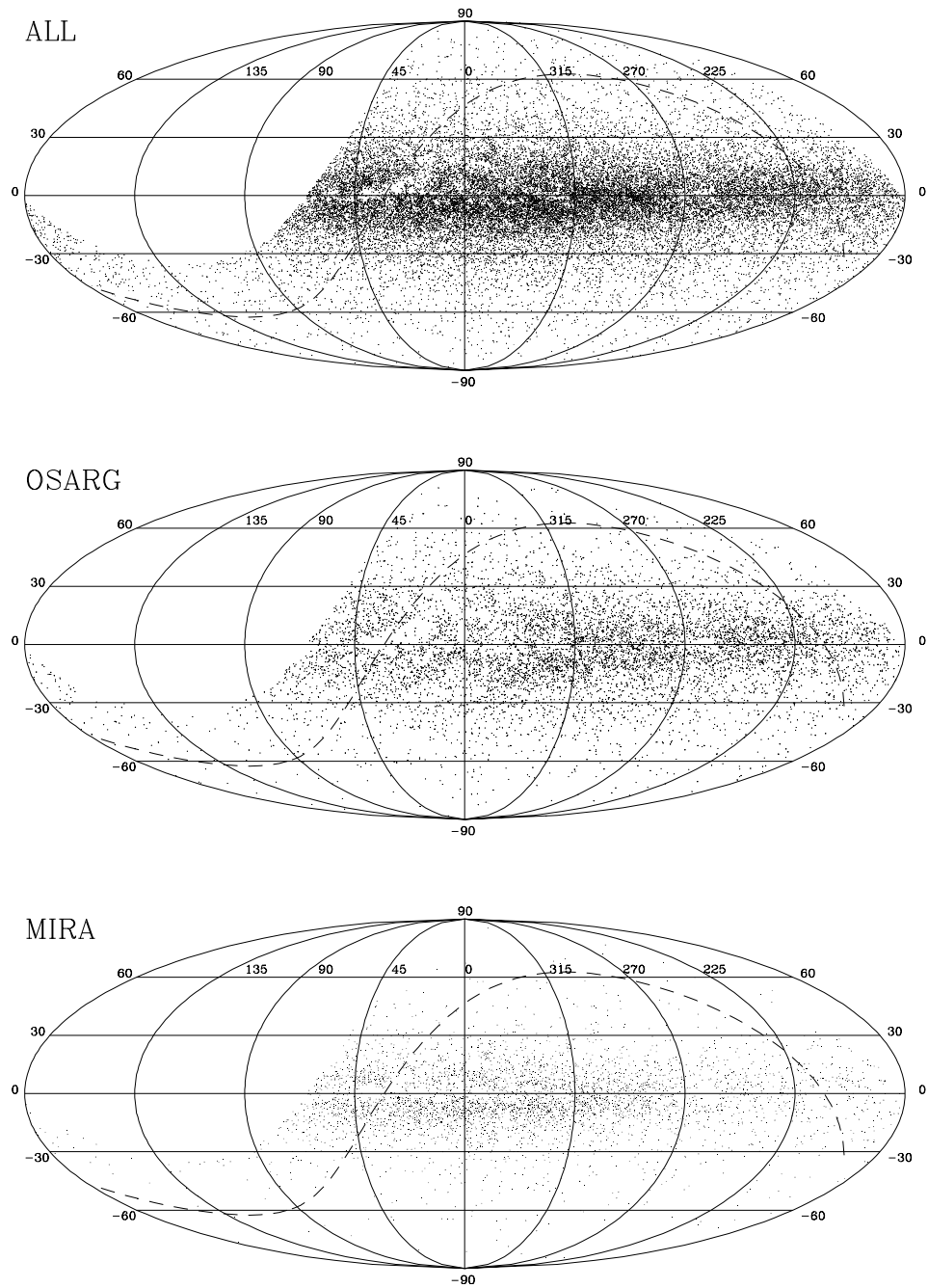


Fig. 3. Distribution of variable stars of the ASAS Catalog of Bright Variable Stars in the *I*-band in Galactic coordinates.

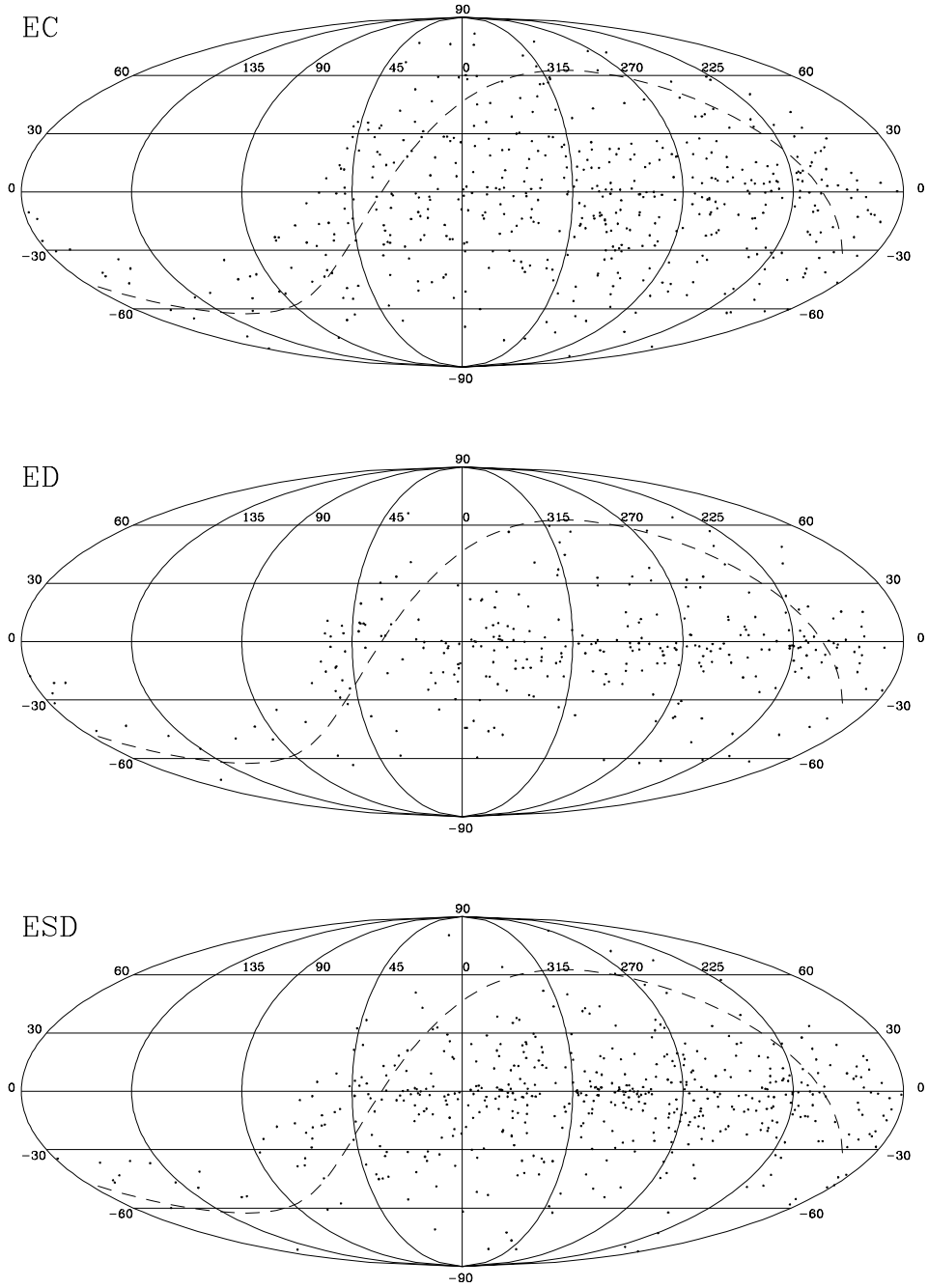


Fig. 4. Distribution of eclipsing binaries of the ASAS Catalog of Bright Variable Stars in the *I*-band in Galactic coordinates.

4. The ASAS Catalog of Bright Variable Stars in the *I*-band

The main purpose of this research was to create a homogeneous catalog of variable sources in the major part of the sky (south of $+28^\circ$), complete to the 9 mag (limit bright enough to detect a star variability down to amplitude 0.02 mag in the ASAS data).

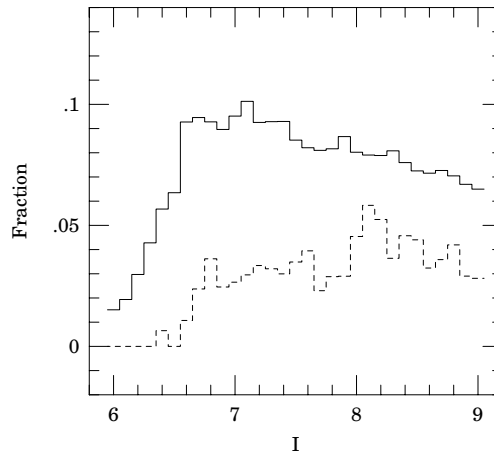


Fig. 5. Fraction of the stars that turned out to be variable in the *I*-band (solid line). Fraction of the variable stars that have small amplitudes (dashed line).

Completeness of the catalog may be inferred from the Fig. 5, where histograms of ratio of variable to all stars and small amplitude ($\Delta I < 0.05$ mag) to variable stars are plotted against the *I* magnitude. Stars brighter than $I = 6.6$ mag are saturated, causing large scatter of measurements, hence fraction of the variable stars is much lower here – small amplitude stars are practically missing. Fraction of the detected variable stars drops (from 0.095 at $I \approx 7$ mag to 0.065 at $I \approx 9$ mag) also toward fainter magnitudes.

The complete ASAS Catalog of Bright Variable Stars in the *I*-band consists of tabular and graphic material.

The list of variable stars contains the following fields:

- ASASID – ASAS identification constructed from the star's α_{J2000} and δ_{J2000} in the form: *hhmmss±ddmm.m*
- *P* – period in days; for irregular variables this is the characteristic time-scale of variation
- HJD0 – epoch of maximum (for pulsating) or minimum (for eclipsing) brightness
- *I* – average brightness of the star in the *I*-band
- AMP – amplitude of *I*-band variation
- TYPE – variability type; one or a combination of EC, ED, ESD, DSCT, DCEP, CW, ACV, BCEP, RARB, RRC, MIRA, OSARG, MISC

- ASASID-V – ID in the ASAS V-band catalog of the variable stars
- GCVS-ID – object name in the GCVS catalog
- GCVS-P – period in the GCVS catalog
- GCVS-V – brightness in the GCVS catalog
- GCVS-TYPE – variability type in the GCVS catalog
- SIMBAD-ID – object name in the SIMBAD database
- SIMBAD-TYPE – object type in the SIMBAD database
- J – 2MASS J brightness
- H – 2MASS H brightness
- K – 2MASS K brightness
- DIST – distance to the 2MASS counterpart
- RA – right ascension of the 2MASS counterpart
- DEC – declination of the 2MASS counterpart
- 2MASS-ID – ID of the 2MASS counterpart
- NC – number of 2MASS objects within 30 arcsec radius

For each star we have provided a text file containing measurements and graphical file containing raw and folded light curves.

The catalog, data and graphic material can be downloaded over the Internet from:

<http://www.astrouw.edu.pl/~gp/asas/AsasBrightI.html>

5. Conclusions

We have searched archival ASAS data collected in the I -band between 2002 and 2009 for variability of bright stars. All stars with $I < 9$ mag were extensively investigated, what led to the detection of 27 705 variable stars south of $+28^\circ$. 7842 of them were not known to be variable before.

As it could have been anticipated, I -band search is best suited for a study of red or reddened objects. Hence most of the discovered stars belong to OSARG and MIRA classes. Also, many of the MISC variables are in fact red, semi-regular variable stars with large amplitudes. Nevertheless several hundred of new eclipsing, Cepheid and α^2 CVn stars have also been discovered. Almost 10% of the stars seem to be variable in the I -band, a fraction considerably larger than in bluer bands.

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